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AUSTENITIC NICKEL-CHROMIUM-MOLYBDENUM-SILICON ALLOY WITH HIGH
CORROSION RESISTANCE TO HOT CHLORIDE-CONTAINING GASES AND
CHLORIDE

The invention relates to an austenitic nickel-chromium-molybdenum-silicon alloy with additions of silicon.

In plants and aggregates where hot chlorine-containing gases and chloride-containing deposits occur (chemical plants, thermal waste-disposal facilities, in particular when recycling special waste, plants for the recycling of biomass, large diesel engines, exhaust systems of automobiles) ferritic boiler construction steel is used at temperatures up to 400°C. At higher temperature, nickel-chromium-molybdenum alloys with 21.5% chromium, 9% molybdenum, 3.7% niob, 2.5% iron, and the remainder nickel and unavoidable impurities (German material number 2.4856) are used (steel code 1995)

The alloy with the material number 2.4856 is however difficult to process. In addition this alloy suffers a considerable ductility losses at temperatures above 500°C, a loss which may result in the formation of cracks in pressure-carrying components and/or those subjected to heavy mechanical stress. To a certain extent, the start of precipitation of the ductility-reducing precipitation can be delayed by lowering the iron content.

Measures leading to a clear rise in ductility are indicated in the international patent application WO 95/31579 in which a new alloy is described on basis of the alloy according to material number 2.4856 which distinguishes itself through increased hot and cold formability and a greater ductility.

The new alloy described in this publication has still some disadvantages. Thus the indicated ductility-raising measures cause the corrosion resistance to gases containing great amounts of chlorine and coatings containing chloride to drop below that of alloy with the material number 2.4856. Already with this alloy, high corrosion rates occur for reasons constantly rising process and exhaust gas temperatures due to the increase in effectiveness. Alloys of the type 2.4856 are in addition subject to heat corrosion by sulphate-containing deposits, so that a considerable need for an alloy of a different type, with improved resistance to high-temperature corrosion exists.

It is the object of present invention to develop an alloy with a resistance to chlorine gas corrosion and to chloride-containing coatings significantly superior to that of the state of the art, while at the same time providing increased resistance to sulphate corrosion while possessing high ductility over the entire temperature range up to 1000°C.

The object is attained by means of a silicon-containing nickel-chromium-molybdenum alloy which is made up of the following components (in mass %):

Cr	18 - 22 %
Mo	6 - 10 %
Si	0.6 - 1.7 %
C	0.002 - 0.05 %
Fe	1 - 5 %
Mn	0.05 - 0.5 %
Al	0.1 - 0.5 %
Ti	0.1 - 0.5 %
Mg	0.005 - 0.05 %
Ca	0.001 - 0.01 %
V	max. 0.5 %
P	max. 0.02 %
S	max. 0.01 %
B	0.001 - 0.01 %
Cu	max. 0.5 %
Co	max 1 %
Nb	max. 0.5 %

Hf and/or Y and/or Zr and/or rare earth elements - 0.02 - 0.5%
the remainder being nickel and impurities caused by the melting process.

The alloy according to the invention is clearly more high-temperature corrosion resistant to chlorine-containing gases, chloride-containing ash, deposits and salt compounds than those of the state of the art, while at the same time being corrosion resistant to sulphate corrosion and wet corrosion and is at the same time highly ductile.

Preferred further developments of the object of the invention are to be found in the sub-claims.

A preferred alloy is composed of the following alloy components (in mass percentages) :

Cr	18 - 20 %
Mo	8 - 9.0 %
Si	0.7 - 1.1 %
C	0.002 - 0.15 %
Fe	2.5 - 3.5 %
Mn	0.05 - 0.1 %
Al	0.1 - 0.3 %
Ti	0.1 - 0.4 %
Mg	0.005 - 0.15 %
Ca	0.001 - 0.005 %
V	max. 0.1 %
P	max. 0.002 %
S	max. 0.001 %
B	0.001 - 0.001 %
Cu	max. 0.5 %
Nb	max. 0.5 %
Hf and/or Y and/or Zr and/or rare earth elements - 0.03 - 0.06%	
the remainder being nickel and impurities caused by the melting process.	

The alloy is advantageously suited on the one hand for the production of pipes, in particular composite pipes, sheet metal, band material, foils, wires as well as items made from these semi-products, and is furthermore suitable as corrosion protection in form of applied welding or plating.

The advantageous characteristics of the alloy according to the invention appear in the following examples of embodiments. Table 1 shows for example analyses of batches of the alloy according to the invention (A-F) as well as the comparison alloys (G, H) other than the combination according to the invention (G, H). The alloy 2.4856 was used for comparison. All alloy variants were produced from cast blocks by means of hot rolling followed by cold rolling at room temperature.

The resistance of the alloy according to the invention to chloride corrosion is depicted in Figs. 1 and 2. For the tests, polished and clean test coupons of different test alloys were submerged in an aqueous solution of 1 mol/l NaCl, 0.1 mol/l CaCl₂ and 0.25 mol/l NaHCO₃, dried at 60°C and then aged in the air at 750°C for 240 hours. This test simulates the stresses which appear e.g. in exhaust systems of car engines (at bellows for uncoupling catalytic converter and engine). Fig. 1 shows the disappearance of metal, Fig. 2 shows the metallographically determined corrosion effect at the end of the test. In tests it was found surprisingly that the resistance to chloride corrosion could be markedly improved over that of alloy 2,4856 by the addition of silicon in quantities from 0.6 and 1.7%.

The advantageous influence of silicon can also be seen in Fig. 3 which shows the metallographically determined corrosion effect on samples which were aged in a complex medium (chlorine-containing synthetical waste combustion gas (2.5 g/m³ HCl, 1.3 g/m³ SO₂/ 9% O₂, the remainder N₂) while at the same time adding chloride-containing boiler ash) for over 1000 hours at 600°C. By comparison with the low-silicon batch (e.g. G) the alloy containing silicon according to the invention suffered markedly less corrosion effect.

Fig. 4 shows the corrosion effect after a cyclic 1008 hour aging of samples which were coated before aging at 750° C in a chlorine and sulfur dioxide-containing atmosphere with a coat of Na₂SO₄/KCl. This test serves to test resistance to sulfate corrosion. As can be seen in the figure, the degrees of corrosion in the alloys according to the invention are markedly lower also with this

corrosion stress than the alloy 2,4856 used at this time under such corrosion conditions.

The outstanding characteristics of the alloy according to the invention can be attributed to the silicon additions and to the coordination of the alloy elements molybdenum, chromium and iron.

The silicon contents of the alloy according to the invention should be between 0.6 and 1.7 %, since the corrosion-inhibiting effect of silicon no longer occurs with lower silicon contents and since embrittling silicides and a marked loss in ductility, in particular at middle temperatures (500 - 800°C) are to be expected with higher contents in silicon. With silicon contents between 0.5 and 1.7 % the notch bar test toughness, measured in ISO-V Charpy tests, does not drop below 100 J/cm as shown in Fig. 5, even after aging for 1000 hours at 600°C.

The molybdenum content of the alloy according to the invention is limited to 10% because, as shown in Fig. 4, the vulnerability to sulphate corrosion increases with molybdenum contents. A minimum molybdenum content is required in order to avoid wet corrosion in case of a drop below the dew point.

The chromium content of the alloy according to the invention should be between 18% and 22% in order to ensure sufficient corrosion resistance. Greater contents in chromium render the workability of nickel-chromium-molybdenum alloys markedly more difficult.

The contents in phosphor and sulfur should be kept as low as possible, as these interfacially active

elements lower the high-temperature corrosion resistance as well as the ductility of the alloy.

The alloy according to the invention can be used for bands, foils, sheets, pipes (seamless or welded), wires, as application weldment, as application plating or as composite piping.

The production of the alloy according to the invention may be effected by means of block casting or also continuous casting after melting in a vacuum induction furnace or after open melting. The alloy may be remelted but this is not absolutely necessary. Hot-forming is effected by forging, hot rolling or extruder, while cold forming is effected by cold rolling, wire pulling or putting through a pilger mill. The production of combination materials, e.g. plating on carbon steel, can be done by means of one of the conventional application welding processes, through cold or hot rolling of sheets or bands, through explosive cladding or through one of the conventional processes for the production of bimetal pipes.

Thanks to its excellent resistance to chlorination, the alloy is especially suitable in form of band or sheet, pipe or plating material for utilization in hot, chlorine-containing gases, or in the presence of chloride-containing coatings, such as occur in chemical industrial plants, in plants for the thermal treatment of chlorine-containing chemical waste and contaminated soil as well as in car exhaust gas systems (bellows for the uncoupling of exhaust catalytic converter and engine). The excellent resistance of the alloy to complex corrosive salt deposits (boiler ash) renders the alloy also suitable for the utilization as plating and construction material in plants for thermal waste removal,

in large diesel engines, in plants for the obtention of energy from biomass and in plants of the cellulose industry.

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